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MEASUREMENTS OF MILLIMETER WAVE RADAR TRANSMISSION  
AND BACKSCATTER DURING DUSTY INFRARED TEST II (DIRT II)

by  
F. C. Petito  
and  
E. W. Wentworth

May 1980

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U.S. ARMY ELECTRONICS R&D COMMAND  
NIGHT VISION & ELECTRO-OPTICS LABORATORY  
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DELNV-TR-0011	2. GOVT ACCESSION NO. AD-A086288	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MEASUREMENTS OF MILLIMETER WAVE RADAR TRANSMISSION AND BACKSCATTER DURING DUSTY INFRARED TEST II (DIRT II)	5. TYPE OF REPORT & PERIOD COVERED Final report	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) F. C. Petito E. W. Wentworth	8. CONTRACT OR GRANT NUMBER(s) 11 May 80	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Night Vision and Electro-Optics Laboratory	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (16) 63710A, 1E263710DK70-13 032CJ	
11. CONTROLLING OFFICE NAME AND ADDRESS Night Vision and Electro-Optics Laboratory Advanced Concepts Division Fort Belvoir, Virginia 22060	12. REPORT DATE May 1980	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 1. 4. 2.	13. NUMBER OF PAGES 40	
	15. SECURITY CLASS. (of this report) Unclassified	
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Millimeter Wave Transmission and Backscatter 95 GHz DIRT II Transmission Backscatter		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Recently there has been much interest expressed within the U.S. Army Electronics Research and Development Command to determine the ability of millimeter wave radar to perform target acquisition during degraded visibility conditions. In this regard, one of the primary issues of concern has been the potential of high-explosive artillery barrages to obscure the battlefield from millimeter wave radar systems. To address this issue the Night Vision and Electro-Optics Laboratory (NV&EOL) in conjunction with the Atmospheric Sciences Lab (Continued)		

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(ASL) conducted 95-GHz millimeter wave radar measurements during the latter's Dusty Infrared Test II (DIRT II). This test was held at White Sands Missile Range, NM 18-28 July 1979. Millimeter wave transmission and backscatter measurements were performed during singular live firings and static detonations of 155-mm and 105-mm high-explosive artillery rounds in addition to static detonations of C-4 explosives. A brief description of the millimeter wave portion of the test and instrumentation is given. The data along with some preliminary conclusions are presented.

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## PREFACE

The authors wish to express their appreciation to the following people: Dr. J. Tegnalia of DARPA, who provided a large portion of the radar equipment used in this test; to the ASL Test Director, Mr. Bruce Kennedy, and test personnel, who provided invaluable support at the test site; and to the Millimeter Wave personnel, Mr. G. Klauber and Mr. B. Patterson for obtaining the data under adverse conditions.

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## CONTENTS

Section	Title	Page
	PREFACE	iii
	ILLUSTRATIONS	v
	TABLES	vii
I	INTRODUCTION	1
II	TEST SITE	1
III	INSTRUMENTATION	3
IV	METHODOLOGY	8
V	DATA COLLECTION AND PRELIMINARY ANALYSES	12
VI	SUMMARY	27

## ILLUSTRATIONS

Figure	Title	Page
1	Layout of the Test Site Relative to Millimeter Wave Transceiver	2
2	Profile of the Test Range Along the Center of the Millimeter Wave Beam	3
3	NV&EOL/DARPA Mobile Millimeter Wave Measurement Van on Site During DIRT II	5
4	Block Diagram and Specifications of the 95-GHz Instrumentation Radar	6
5	Block Diagram of the Two NV&EOL Radar Data Acquisition and Reduction Systems	7
6	Crater Locations of Artillery-Fired Projectiles Overlaid with the Millimeter Wave Antenna Beam Pattern	10
7	Crater Locations of Statically Detonated Projectiles/Explosives Overlaid with the Millimeter Wave Antenna Beam Pattern	10
8	Example of a Receiver Calibration Plot. Output Voltage vs. RF Attenuation (Decibels) for the IF Logarithmic Amplifier/Detector	11
9	A-Scope Traces (Backscatter vs. Range) at 1-s Increments of Time After Detonation	13
10	Transmission, Backscatter vs. Time for Artillery-Fired Projectiles: (a) 155-mm Projectile, and (b) 105-mm Projectile	17
11	Transmission, Backscatter vs. Time for Three Surface-Detonated 155-mm Projectiles at Locations: (a) CL (b) 10-m East of CL and 20 m East of CL	18
12	Transmission, Backscatter vs. Time for Three Subsurface-Detonated 155-mm Projectiles at Locations: (a) CL (b) 10 m East of CL and 20 m East of CL	19

## ILLUSTRATIONS (Cont'd)

Figure	Title	Page
13	Transmission, Backscatter vs. Time for Two Surface-Detonated 105-mm Projectiles at Locations: (a) CL and (b) 10 m East of CL	20
14	Transmission, Backscatter vs. Time for Two Subsurface-Detonated 105-mm Projectiles at Locations: (a) CL and (b) 10 m East of CL	21
15	Transmission, Backscatter vs. Time for Two Surface-Detonated C4 Explosives at Locations: (a) CL and (b) 10 m East of CL	22
16	Transmission, Backscatter vs. Time for Two Subsurface-Detonated C4 Explosives at Locations: (a) CL and (b) 10 m East of CL	23
17	A Comparison of the Mean Values of Peak Backscatter and Duration Obtained for Surface Explosives with Those Values for Subsurface Explosions	25



## TABLES

Table	Title	Page
1	Survey and Computed Data for Targets and Stations Relative to the Millimeter Wave Transceiver During DIRT II	4
2	Summary of Results of Millimeter Wave Measurements During DIRT II	14
3	Average Values of Maximum Two-Way Attenuation and Associated Recovery Time Which Were Recorded During DIRT II	26

## MEASUREMENTS OF MILLIMETER WAVE RADAR TRANSMISSION AND BACKSCATTER DURING DUSTY INFRARED TEST II (DIRT II)

### I. INTRODUCTION

Recently there has been much interest expressed to determining the ability of millimeter wave radar to perform target acquisition during degraded visibility conditions. In this regard, one of the primary issues of concern has been the potential of high-explosive artillery barrages to obscure the battlefield from millimeter wave radar systems. To address this issue, NV&EOL in conjunction with the Atmospheric Sciences Lab (ASL) conducted 95-GHz millimeter wave radar measurements during ASL's Dusty Infrared Test II (DIRT II). This test was held at White Sands Missile Range, NM, from 18-28 July 1979. Millimeter wave transmission and backscatter measurements were performed during singular live firings and static detonations of 155-mm and 105-mm high-explosive artillery rounds in addition to static detonations of C-4 explosives. A brief description of the millimeter wave portion of the test and instrumentation is given. The data along with some preliminary conclusions are presented.

### II. TEST SITE

A layout of the test site relative to the millimeter wave transceiver is shown in Figure 1. The radar was positioned at the northern end of the test site approximately 6 m west of the North Instrumentation Site (not shown in the figure). The North Instrumentation Site and the South Instrumentation Site are the end points of the optical path, a segment of which is depicted in Figure 1. CR(C1), CR(C2), and CR(C3) are the positions of three corner reflectors having cross sections of 17.8 dbsm, 30.2 dbsm and 25.2 dbsm, respectively. Although not shown, additional corner reflectors were positioned east and west of the beam center for orientation purposes. The beam width of the millimeter wave antenna was  $0.4^\circ$  and the line in the figure connecting the millimeter wave radar and CR(C2) represents the location in azimuth of the beam center along the test range and is 2151.2 m long. The figure shows that the optical path and the millimeter wave radar beam center intersect at approximately the center of the optical path and that they diverge by no more than  $0.05^\circ$  in azimuth over the region of interest. The Detonation/Impact Zone, also shown in Figure 1, is a region from 1100 to 1260 m with an angular displacement of approximately  $-1^\circ$  to  $+0.5^\circ$  about the beam center. This is the region into which the artillery fired and in which the static rounds were detonated.

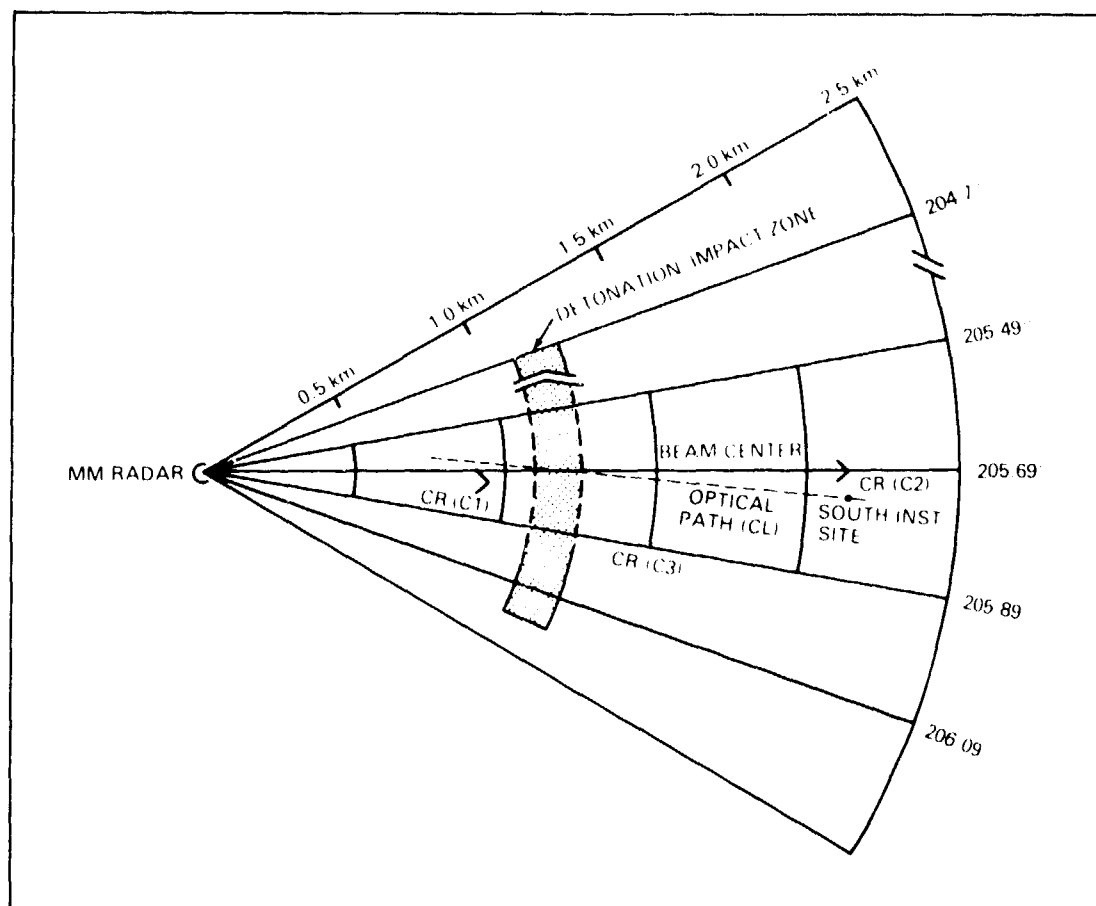


Figure 1. Layout of the test site relative to millimeter wave transceiver.

A profile of the range from the millimeter radar to CR(C2) is shown in Figure 2. The positions of the corner reflectors within the beam are illustrated. The corner reflectors CR(C1) and CR(C2) were positioned atop telescoping dielectric poles, the heights of which were selected to ensure that the main portion of the beam did not intercept the ground and result in spurious signals; i.e., multipath effects. CR(C3) was placed on 22 July 79 in order to measure transmission along a different angular position. The beam center which is the millimeter wave transmission path to CR(C2) is 11.1 meters above the center of Detonation/Impact Zone and is defined as transmission path 2, whereas the transmission path to CR(C3) is 4.5 meters above the center and is defined as transmission path 3.

Survey coordinates expressed in the White Sands Transverse Mercator designation were provided by ASL. Using this survey data, azimuth angles, depression angles and ranges relative to the millimeter wave radar were computed, plotted, and are shown in Table 1.

It is appropriate to mention that the test site was relatively free of clutter and the corner reflectors employed provided excellent signal-to-clutter ratios.

### III. INSTRUMENTATION

The mobile millimeter wave measurements van on location at the test site is shown in Figure 3. It is a self-contained facility housing two 95-GHz radars and two computer-based data acquisition and reduction systems.

A block diagram and the specifications of the instrumentation radar used to make the radar measurements are shown in Figure 4. It is a pulsed noncoherent radar using an Amperex 287 magnetron as the transmitter. It employs a superheterodyne receiver with a temperature stabilized OKI Klystron as the local oscillator. In the receiver channel between the balanced mixer and the circulator, a direct-reading precision attenuator (TRG Model No. 510) is located. This component enables the operator to perform a calibration of the receiver and when used with a reference corner reflector provides absolute calibration in terms of cross section. The radar's dynamic range is determined by the intermediate frequency (IF) amplifier. Amplifiers with dynamic ranges of 60 dB and 15 dB were available for the test. The detected radar signal is displayed using an A-scope and is also sent to the data acquisition systems (DAS).

A block diagram of the two NV&EOL data acquisition and reduction systems is illustrated in Figure 5. As can be seen, the radar video is routed in parallel to DAS No. 1 and DAS No. 2. DAS No. 1 is a minicomputer-based data acquisition system having the following principal characteristics:

**TABLE 1**  
**LIST OF SURVEY AND COMPUTED DATA FOR TARGETS AND STATIONS**  
**RELATIVE TO THE MILLIMETER WAVE TRANSCIEVER DURING DIRT II**

LOCATION	RANGE (M)	Az (deg)	E1 (M)	HEIGHT (M)	DEPRESSION ANGLE (deg)
MMW XTMR	0	0	1292.0	2.44	—
4 CR(C1)	950.0	205.73	1281.6	9.98	.17
CENTER	1197.6	—	1280.2	0	—
CR(C3)	1469.8	205.82	1280.5	2.03	.46
CR(C2)	2151.2	205.69	1281.5	8.05	.13
SOUTH INSTR.	2200.4	205.74	1282.20	—	—

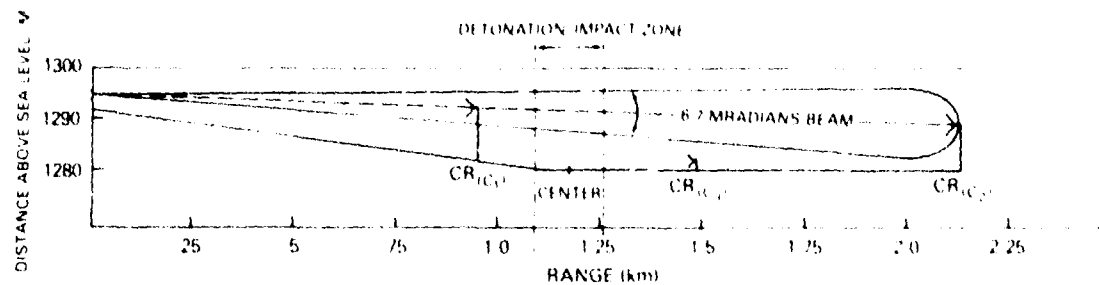


Figure 2. Profile of the test range along the center of the millimeter wave beam.

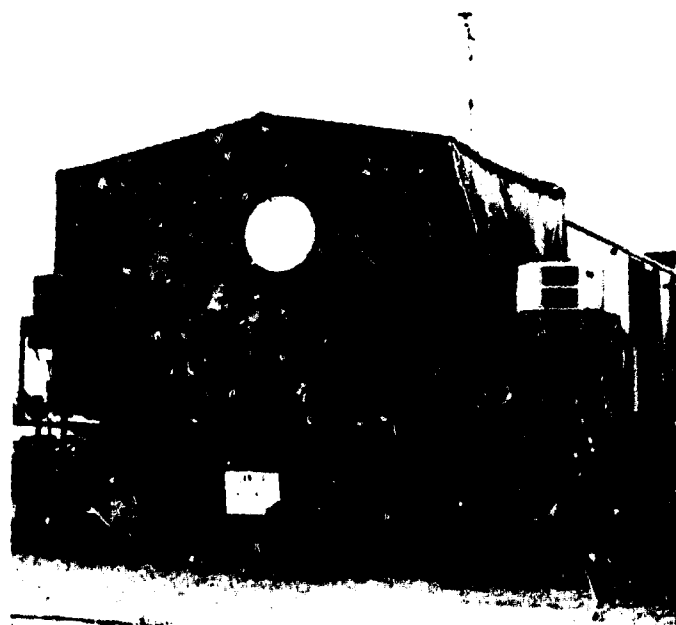


Figure 3. NV&EOL/DARPA mobile millimeter wave measurement van on site during DIRT II.

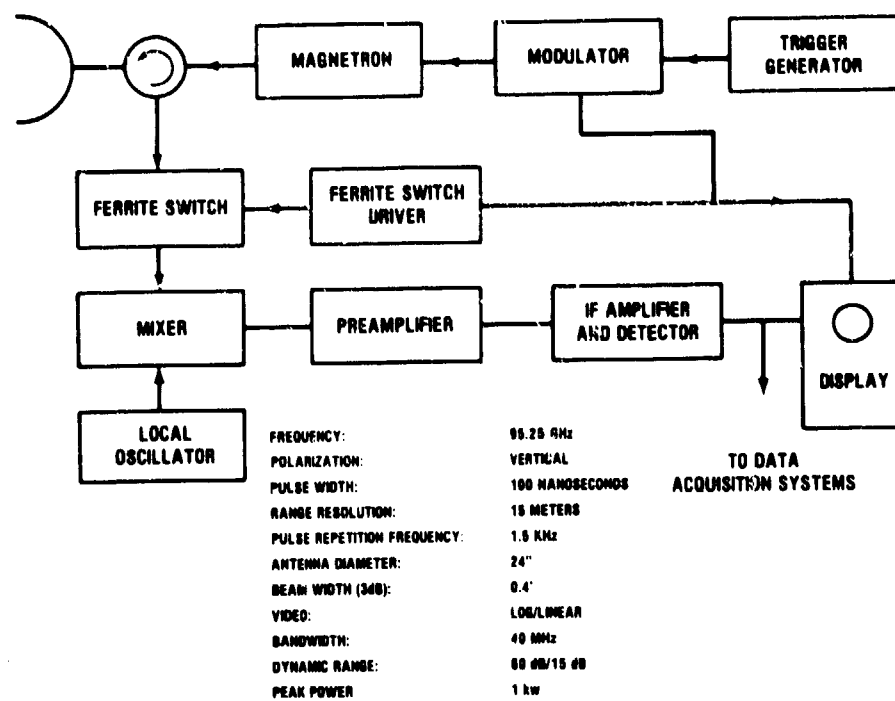


Figure 4. Block diagram and specifications of the 95-GHz instrumentation radar.

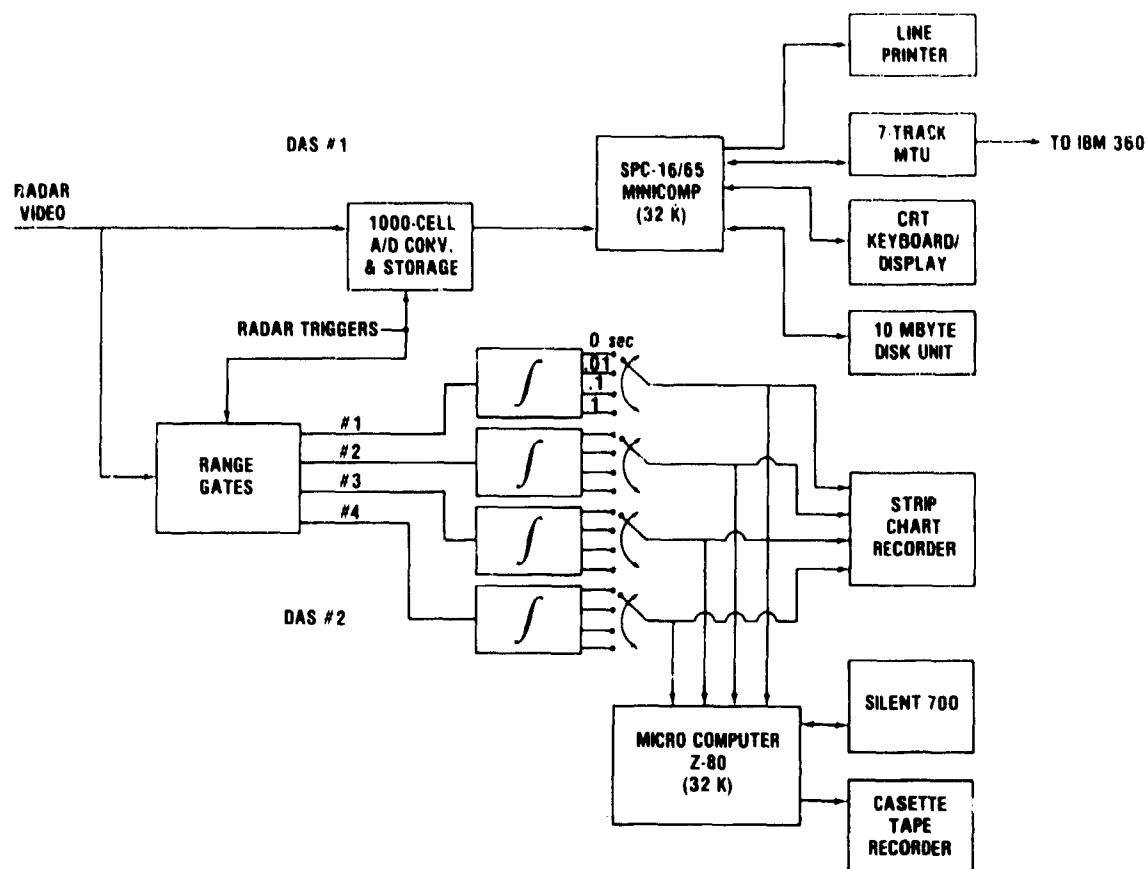


Figure 5. Block diagram of the two NV&EOL radar data acquisition and reduction systems.



1. Operator interactive software.
2. Variable high-speed analog-to-digital converter with a maximum coverage of 1000-range cells per pulse.
3. Single-pulse or digital-integrated video data collection.
4. On-site statistical data reduction when survey data are available.
5. IBM 360 compatible digital tape generation.

In DAS No. 2, the radar video is first range gated and then integrated. The output of the integrator is routed in parallel to both a strip-chart recorder and the microcomputer.

The range gate unit has a total of four continuously variable range gates. Each range gate has four outputs corresponding to 0-, 0.01-, 0.1-, 1.0-s integration time constants. The 0.1-s time constant was selected as a reasonable compromise between noise reduction and response time.

The instrumentation radar is manually positioned in azimuth and elevation. The system is mounted on a Hauser turntable which provides a readout of the azimuth angle to within an accuracy of 4 s. An elevation shaft encoder provides the depression angle to within  $0.05^\circ$ .

A scanning 95-GHz radar was also used during this test to qualitatively observe the backscatter from the exploding projectiles on a PPI display and to perform ground mapping. The only differences in specifications between this radar and the instrumentation radar are that it has an 45.7-cm (18-in.) parabolic antenna and it operates at a frequency of 95.75 GHz. No interference was observed between the two radars when they were operating simultaneously. However, the use of the scanning radar was discontinued after the first day of testing when it was observed that the duration of attenuation and backscatter effects was so brief that scanning became impractical.

#### IV. METHODOLOGY

Millimeter wave transmission and backscatter measurements were performed during live firings and static detonations of 155-mm and 105-mm high-explosive artillery projectiles as well as static detonations of C4 explosives. The tube-delivered 155-mm and 105-mm projectiles (designated Arty A and Arty B tests, respectively) were fired singularly with the countdown for the next round beginning as soon as the optical path returned to unity transmission. In this manner, the firings of the high-explosive projectiles were completed within one day.

In Figure 6, the locations of the craters formed by the impacting rounds have been drawn. The beam pattern of the millimeter wave antenna has been overlayed in order to illustrate the location and dispersion of the impacting rounds during the millimeter wave measurements. (The identification of the craters is a best estimate based on visual observation and backscatter data.)

The schedule of static detonations was announced daily; 155-mm and 105-mm high-explosive projectiles and C4 explosives were detonated singularly (designated A, B, and E tests, respectively) lying on or below the surface. In Figure 7, the locations of the craters formed by the exploding rounds have been overlayed with the millimeter wave antenna beam pattern. As can be seen, the locations of the detonations were systematically varied. This was done to ensure that the exploding projectile/C4 generated its cloud from previously undisturbed soil and to measure the effects on propagation of the lateral displacement of the detonation from the optical path. The choice of an east or west displacement was made based on wind direction to ensure that the resultant cloud drifted across the optical path.

At the start of each day of testing, the instrumentation radar was made operational. The millimeter wave beam was aimed at CR(C2) and the radar echo was maximized. This was accomplished by adjusting the range gate position and the azimuth and depression angles while monitoring the range gated video on the strip-chart recorder.

Following this, the three remaining range gates of DAS No. 2 were positioned. One range gate was positioned over CR(C3) in order to measure relative transmission along path 3. Another was positioned over CR(C1) to monitor transmitter output power, and the last was positioned over the center of the Impact/Detonation Zone during live firings or the location of the projectile/explosive during static detonations in order to measure backscatter.

DAS No. 1 was made operational simultaneously by calling up the data collection programs on the minicomputer. The DAS was initialized to collect backscatter data over the range from 800 to 2800 m for 10 s at 0.1-s increments.

A countdown was initiated by the Test Conductor prior to each live firing or detonation. It was during this period that a calibration of RF attenuation (in decibels) versus strip-chart recorder deflection was performed. Another calibration was performed immediately following the explosion. A representative example of these data has been plotted in Figure 8. The DC-coupled Intermediate Frequency (IF) logarithmic amplifier and video detector were used during all data runs.

### DIRT-II CRATER LOCATIONS

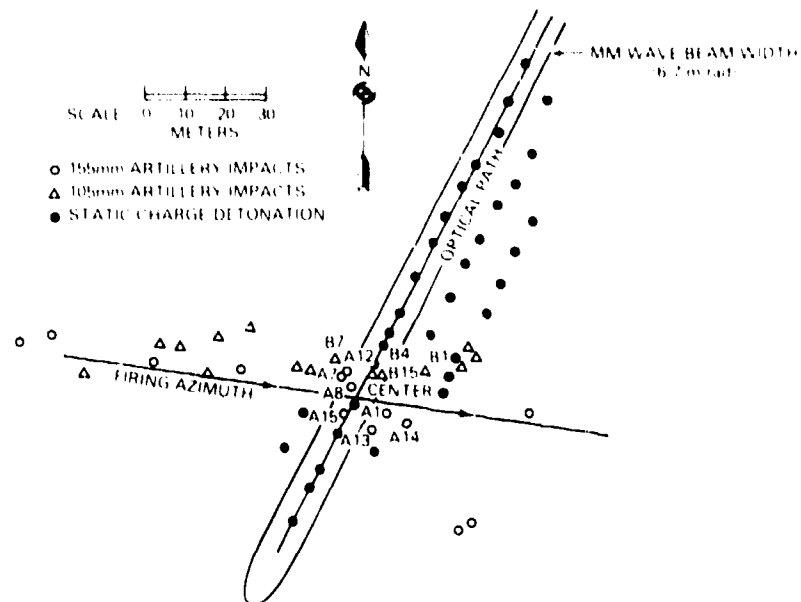


Figure 6. Crater locations of artillery-fired projectiles overlaid with the millimeter wave antenna beam pattern.

### DIRT-II CRATER LOCATIONS

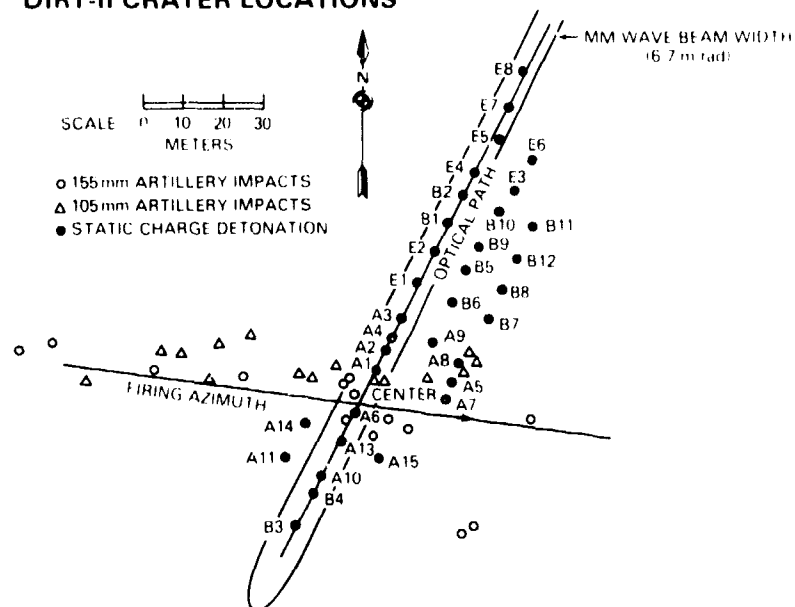


Figure 7. Crater locations of statically detonated projectiles/explosives overlaid with the millimeter wave antenna beam pattern.

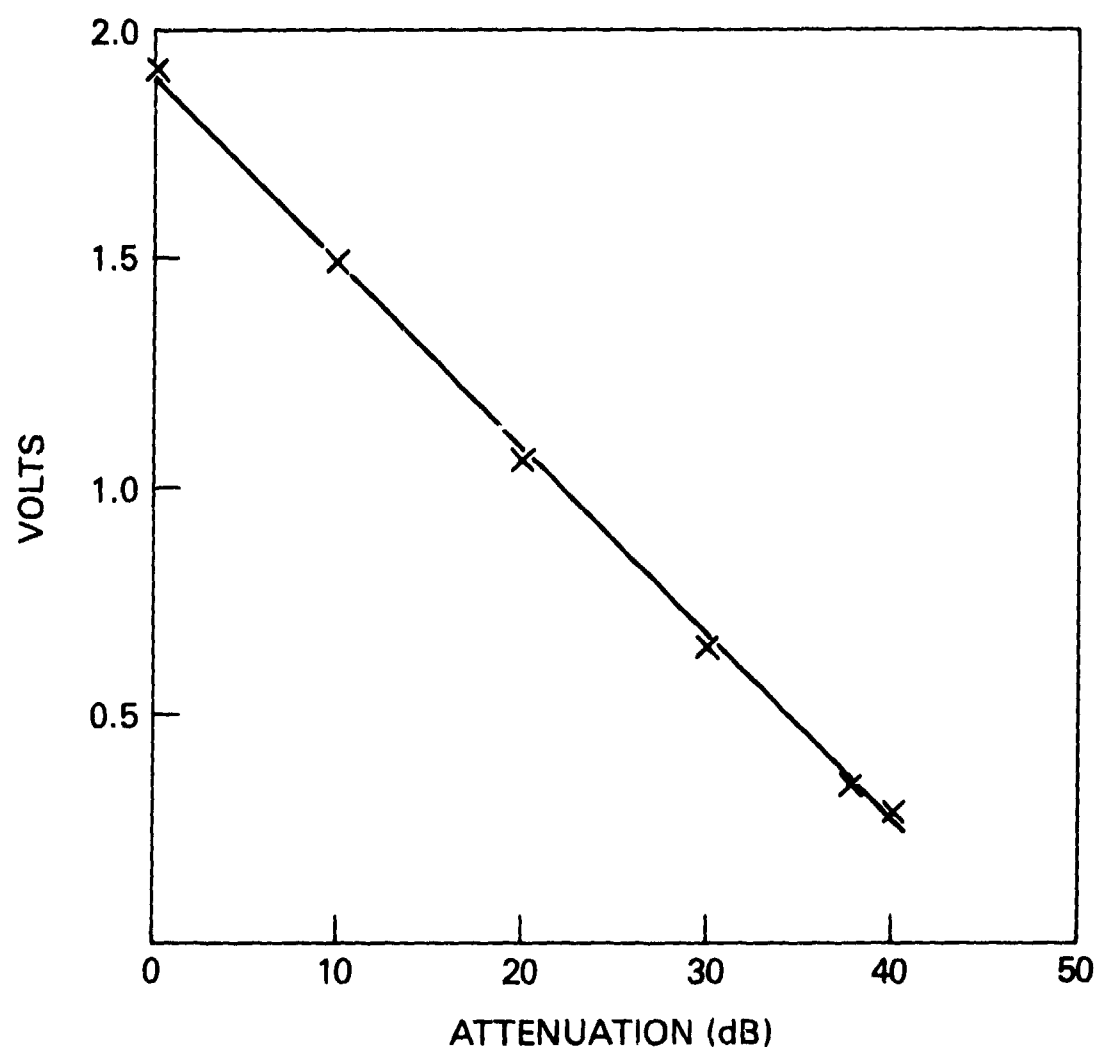


Figure 8. Example of a receiver calibration plot. Output voltage vs. RF attenuation (decibels) for the IF logarithmic amplifier/detector.

## V. DATA COLLECTION AND PRELIMINARY ANALYSIS

An A-scope display of the analog radar signal provided a real-time qualitative indication of the phenomenology associated with an explosion. A-scope traces - i.e., backscatter versus the range relative to ground zero (GZ) - were video-tape recorded and are shown in Figure 9 at 1-s increments of time after detonation for tests A<sub>3</sub>, A<sub>5</sub> and B<sub>3</sub>. As can be seen, the debris, or cloud, which is generated by the explosion and produces measurable backscatter extends for 30 to 45 m and moves in the direction of the wind.

A calibrated digital version of an A-scope trace using DAS No. 1 was also produced and recorded during DIRT II. The radar signal was sampled at 7.5-m intervals along the test range from 900 m to 2500 m and digitized. The digitized signal was integrated and then recorded at 0.1-s increments for 10 s during an explosion. Data were recorded for the following tests:

ARTY B1	ARTY A3*	A13	B6	E1
ARTY B2*	ARTY A7	A14	B5	E2
ARTY B3*	ARTY A8	A15		
ARTY B4*	ARTY A9*	A12		
ARTY B5*	ARTY A12	A11		
ARTY B8*	ARTY A13	A4		
ARTY B12*	ARTY A14	A3		
ARTY B14*	ARTY A15			
ARTY B15				

These data are currently being analyzed. It had been planned originally to collect data using DAS No. 1 for all tests conducted during DIRT II, but a series of power interruptions at the test site caused the minicomputer to fail.

In Table 2, a chronological summary of the results of the millimeter wave measurements performed during DIRT II using DAS No. 2 and other pertinent information are given. The maximum values of relative two-way attenuation recorded along paths 2 and 3 and their respective recovery times have been listed. The recovery time was defined as the time elapsed between detonation and the return of the millimeter wave signal to the level prior to the explosion; i.e., 0 dB. The columns labeled "backscatter" and "duration" list the maximum value of backscatter in decibels relative to one square meter (dbsm) and the elapsed time during which backscatter was measurable.

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\*Impact location was too far from centerline to produce useful data.

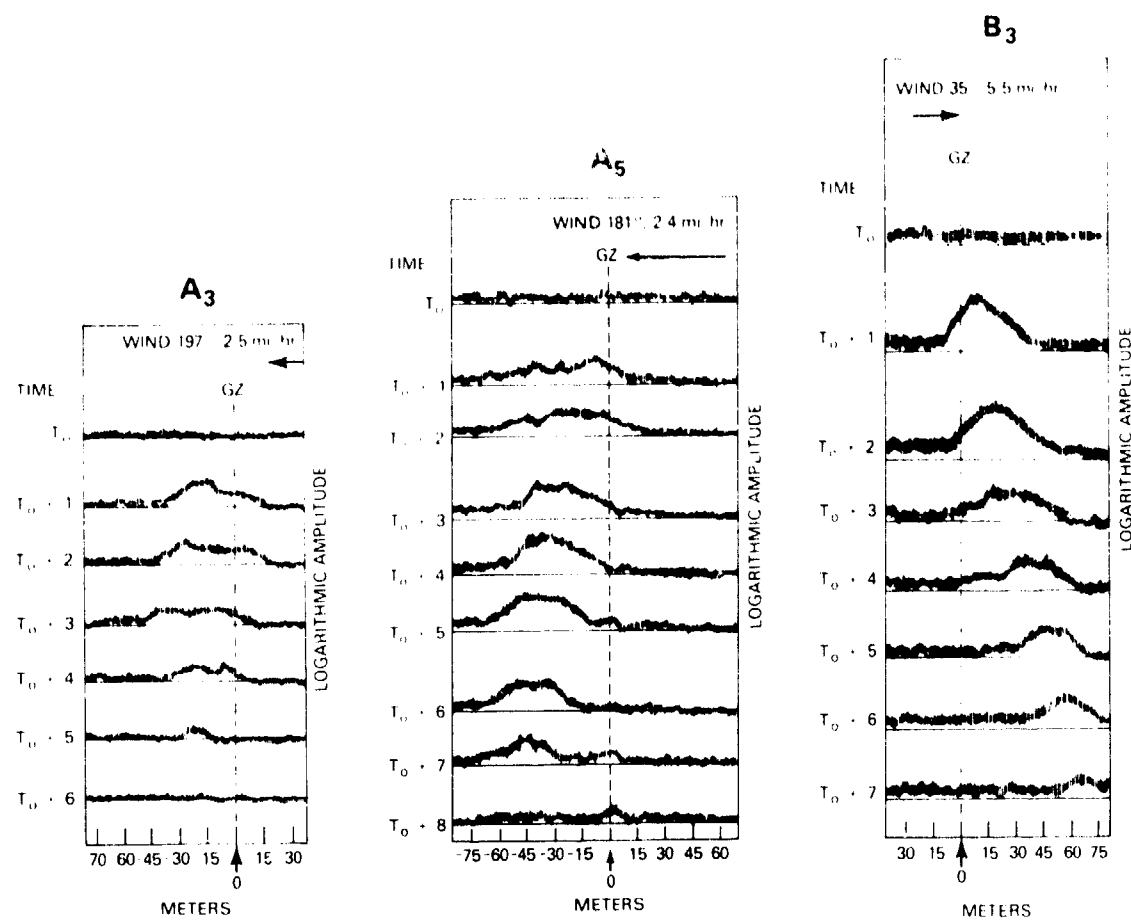


Figure 9. A-scope traces (backscatter vs. range) at 1-s increments of time after detonation.

TABLE 2  
SUMMARY OF RESULTS OF  
MILLIMETER WAVE MEASUREMENTS DURING DIRT II

DATE	TEST	ATTEN (PATH 2)	RECOVERY TIME (PATH 2)	ATTEN (PATH 3)	RECOVERY TIME (PATH 3)	BACKSCATTER	DURATION	COMMENTS
07-18-79	ARTY B1	0	0	-	-	-25.6 dbsm	2.25 sec	NEAR EAST OF CL
07-18-79	ARTY B4	0	0	-	-	-22.06 dbsm	1.7 sec	NEAR EAST OF CL
07-18-79	ARTY B7	0	0	-	-	-25.86 dbsm	1.7 sec	NEAR WEST OF CL
07-18-79	ARTY B15	0	0	-	-	-27.70 dbsm	2.25 sec	NEAR CL
07-18-79	ARTY A1	0	0	-	-	-22.45 dbsm	2.25 sec	NEAR EAST OF CL
07-18-79	ARTY A7	0	0	-	-	-14.21 dbsm	3.65 sec	NEAR CL
07-18-79	ARTY A8	0	0	-	-	-12.92 dbsm	3.25 sec	CL
07-18-79	ARTY A12	0	0	-	-	-22.29 dbsm	3.5 sec	NEAR EAST OF CL, 1/2 BW DOWN
07-18-79	ARTY A13	0	0	-	-	-18.07 dbsm	1.5 sec	CL, 1/2 BW DOWN
07-18-79	ARTY A14	-0	0	-	-	-26.16 dbsm	3.0 sec	NEAR EAST OF CL
07-18-79	ARTY A15	1.0 dB	1.5 sec	-	-	-6.78 dbsm	4.1 sec	CL
07-19-79	A13	1.7 dB	.1 sec	-	-	-24.4* dbsm	N/A	SURFACE, CL
07-19-79	A10	1.1 dB	.1 sec	-	-	-19.4 dbsm	2.0 sec	SURFACE, CL
07-19-79	A14	0	0	-	-	-18.0 dbsm	2.6 sec	SURFACE, 10m WEST OF CL
07-19-79	A15	0	0	-	-	-3.8 dbsm	3.0 sec	SURFACE, 10m EAST OF CL
07-19-79	A12	2.8 dB	1.6 sec	-	-	-4.4 dbsm	3.5 sec	SURFACE, 10m EAST OF CL
07-19-79	A11	0	0	-	-	-	-	NO DATA
07-20-79	A1	0	0	-	-	-27.6 dbsm	2.0 sec	SURFACE, CL
07-20-79	A7	0	0	-	-	-21.0 dbsm	2.3 sec	SURFACE, 20m EAST OF CL
07-20-79	A2	24.4 dB	7.0 sec	-	-	-2.2 dbsm	7.45 sec	BURIED, CL
07-20-79	A5	0	-	-	-	-22.0 dbsm	4.0 sec	BURIED, 20m EAST OF CL
07-20-79	A8	1.0 dB	1.8 sec	-	-	-10.3 dbsm	7.2 sec	BURIED, 20m EAST OF CL
07-20-79	A6	6.9 dB	1.4 sec	-	-	-21.1 dbsm	2.0 sec	AIRBURST, 5', CL
07-21-79	A9	.1 dB	4.6 sec	-	-	-14.1 dbsm	4.5 sec	BURIED, 10m EAST OF CL

\*THIS NUMBER REPRESENTS THE SENSITIVITY FOR THE PARTICULAR TEST.

**TABLE 2**  
**SUMMARY OF RESULTS OF**  
**MILLIMETER WAVE MEASUREMENTS DURING DIRT II**  
**(CONTINUED)**

DATE	TEST	ATTEN (PATH 2)	RECOVERY TIME (PATH 2)	ATTEN (PATH 3)	RECOVERY TIME (PATH 3)	BACKSCATTER	DURATION	COMMENTS
07-21-79	A4	0	0	—	—	-21.6 dbsm	4.0 sec	SURFACE, CL
07-21-79	A3	26.2 dB	4.75 sec	—	—	-3.2 dbsm	6.0 sec	BURIED, CL
07-23-79	B6	0	0	—	—	-20.5 dbsm	1.4 sec	SURFACE, 10m EAST OF CL
07-23-79	B7	—	—	0	0	-25.0 dbsm	.15 sec	SURFACE, 20m EAST OF CL
07-23-79	B8	—	—	0	0	-26.9 dbsm	1.0 sec	BURIED 20m EAST OF CL
07-23-79	B5	—	—	5.0 dB	.7 sec	-16.6 dbsm	9.5 sec	BURIED 10m EAST OF CL
07-23-79	E1	—	—	22.9 dB	3.0 sec	-14.2 dbsm	10.0 sec	SURFACE, CL, 27 lb
07-23-79	E2	—	—	23.84 dB	9.3 sec	+6.8 dbsm	9.3 sec	BURIED, CL, 16 lb
07-24-79	B12	—	—	0	0	-22.6* dbsm	N/A	SURFACE, 20m EAST OF CL
07-24-79	B11	—	—	0	0	-22.9* dbsm	N/A	BURIED, 20m EAST OF CL
07-24-79	B9	—	—	0	0	12.9 dbsm	11.0 sec	BURIED, 10m EAST OF CL
07-24-79	B10	—	—	0	0	-23.0 dbsm	1.25 sec	SURFACE, 10m EAST OF CL
07-24-79	B1	—	—	—	—	—	—	NO DATA
07-24-79	B2	11.7 dB	4.0 sec	6.34 dB	8.0 sec	-2.8 dbsm	7.1 sec	BURIED, CL
07-25-79	B3	8.5 dB	5.0 sec	29.2 dB	3.0 sec	+6.4 dbsm	5.0 sec	BURIED, CL
07-25-79	B4	0	0	10.73 dB	1.8 sec	-9.6 dbsm	2.4 sec	SURFACE, CL
07-25-79	E3	0	0	0	0	-7.4 dbsm	3.55 sec	SURFACE, 10m EAST OF CL
07-25-79	E4	0.6 dB	1.3 sec	3.7 dB	2.0 sec	-29.23 dbsm	1.6 sec	SURFACE, CL
07-25-79	E5	2.6 dB	1.0 sec	18.5 dB	4.2 sec	+0.1 dbsm	3.8 sec	BURIED, CL
07-25-79	E6	0	0	.1 dB	.6 sec	-6.1 dbsm	14.0 sec	BURIED, 10m EAST OF CL
07-26-79	E8	16.0 dB	2.6 sec	28.0 dB	4.0 sec	+2.7 dbsm	5.5 sec	BURIED, CL

\*THIS NUMBER REPRESENTS THE SENSITIVITY FOR THE PARTICULAR TEST.



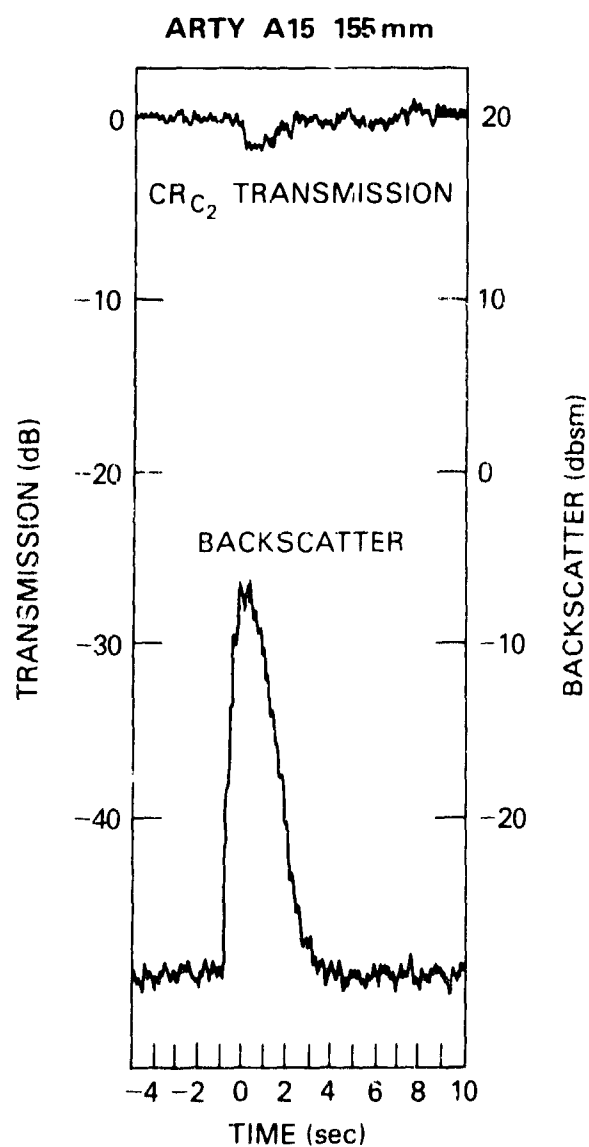
Some further comments are necessary concerning Table 2. As was mentioned early, CR(C3) was positioned at a later date and thus there are no attenuation entries for path 3 until 23 July. During the ARTY A12 and A13 tests, the millimeter wave beam was positioned one-half beam width (BW) (i.e.,  $0.2^\circ$ ) lower in elevation than for any other test. No backscatter was measured to within the entered value of sensitivity for the A13, B12, and B11 tests. The A6 test was an air burst positioned on the centerline (CL) or optical path and was 5 feet above ground level.

The cloud or debris from an explosion produces a time-varying distributed array of scatterers in the path of the millimeter wave radar. It is customary to present distributed clutter data such as this in terms of the surface reflectance ( $m^2/m^2$ ). However, during the period that the scattering cross section was measurable, the radar beam significantly over-resolved the cloud. At the time of writing, cloud size data were not available and, therefore, the data are given in dbsm. Cloud size data will be available in the final report on DIRT II to be published by ASL.

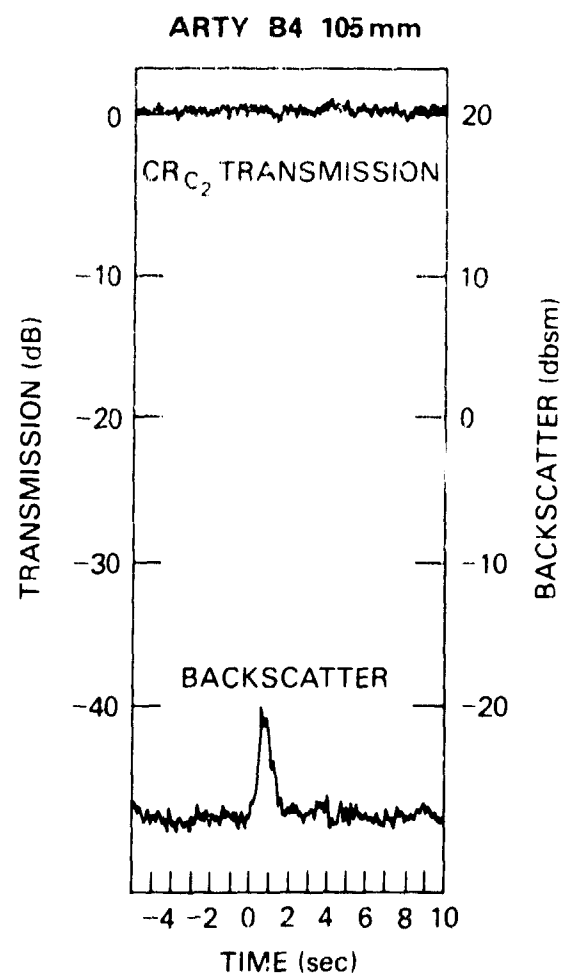
Examples of the data obtained using DAS No. 2 are given in Figures 10 through 16. These are copies of the original strip-chart recordings giving the relative two-way transmission (in decibels) versus time in the upper portion of each figure and backscatter (in dbsm) versus time in the lower portion. These data were acquired using a 0.1-s integration time constant.

The backscatter and transmission data obtained for the ARTY A15 (155-mm) and ARTY B4 (105-mm) tests are presented in Figure 10. These were artillery-delivered projectiles. The values of backscatter and attenuation recorded for the ARTY series of tests were dependent upon the range gate location (center of Impact Zone), wind velocity, and impact location. Due to the distribution in location of the impacting projectiles, care must be exercised when interpreting the results of the ARTY series of tests. However, the value of peak backscatter and the mean duration were greater for the ARTY A series (-16.5 dbsm, 3.25 s) than for the ARTY B series (-25.31 dbsm, 2.0 s) and negligible values of attenuation were recorded for either series along path 2.

Examples of the data obtained for surface and subsurface detonated 155-mm projectiles are shown in Figures 11 and 12, respectively. In each figure the data obtained for various displacements relative to the beam center or centerline (CL) are given. In examining the shape of the backscatter curve for detonation on the centerline in Figure 12, it is apparent that the fast rise time results from the explosion hurling debris (i.e., soil) into the air. The slower decay time results from the gradual return of clumps of debris to the ground. The finer particles remain airborne longer but do not have a significant effect on backscatter or transmission. In comparing the backscatter curves obtained for detonation on the centerline with those for detonations displaced



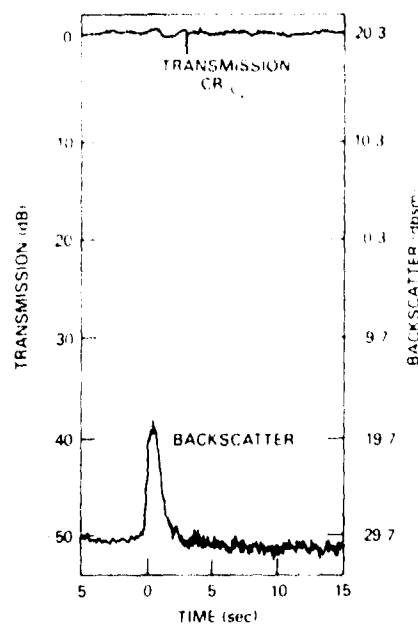
(a)



(b)

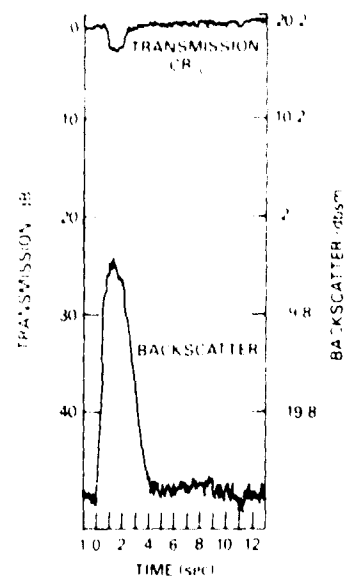
Figure 10. Transmission, backscatter vs. time for artillery-fired projectiles:  
(a) 155-mm projectile, and (b) 105-mm projectile.

A10 155mm



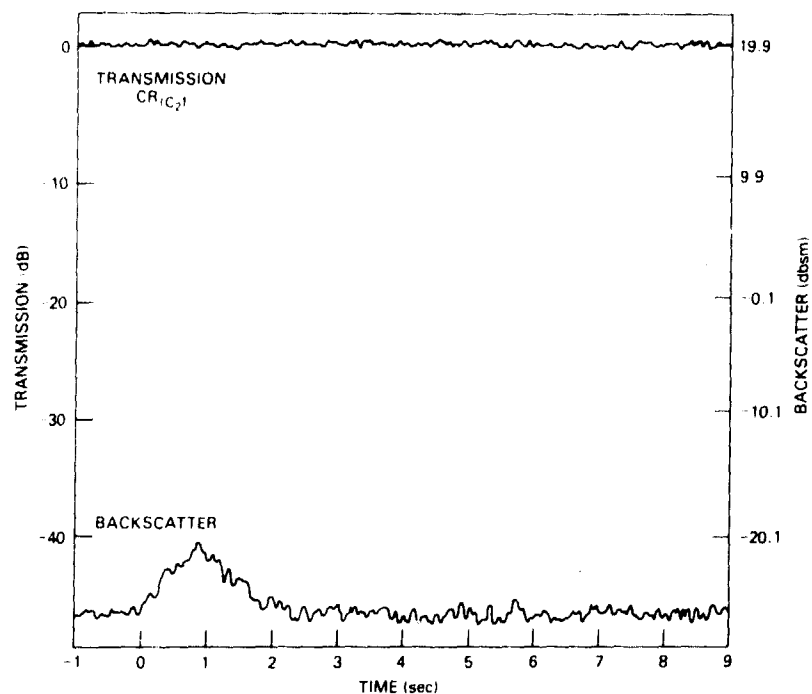
(a)

A12 155mm



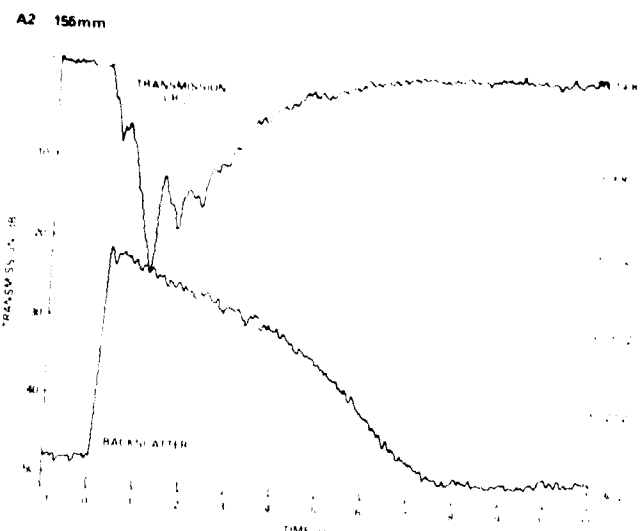
(b)

A7 155mm

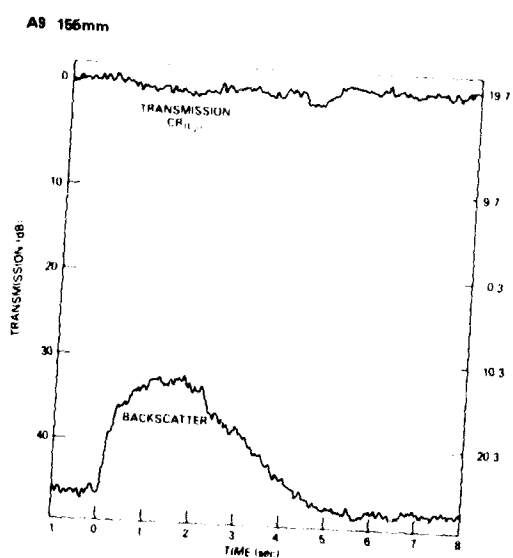


(c)

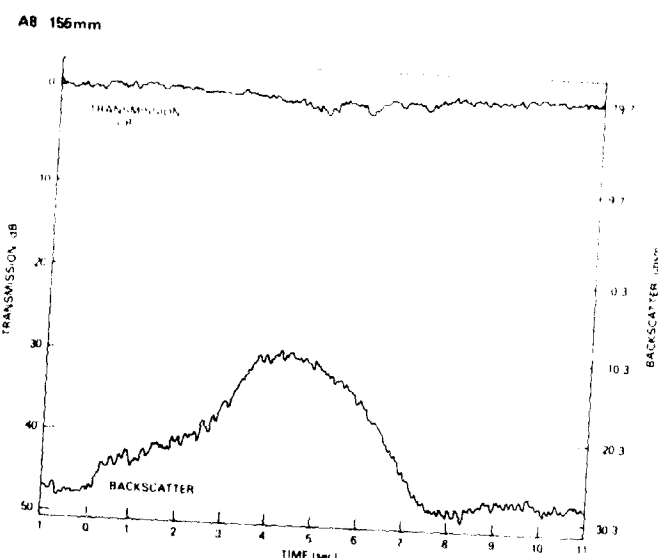
Figure 11. Transmission, backscatter vs. time for three surface-detonated 155-mm projectiles at locations: (a) CL, (b) 10 m East of CL, and (c) 20 m East of CL.



(a)



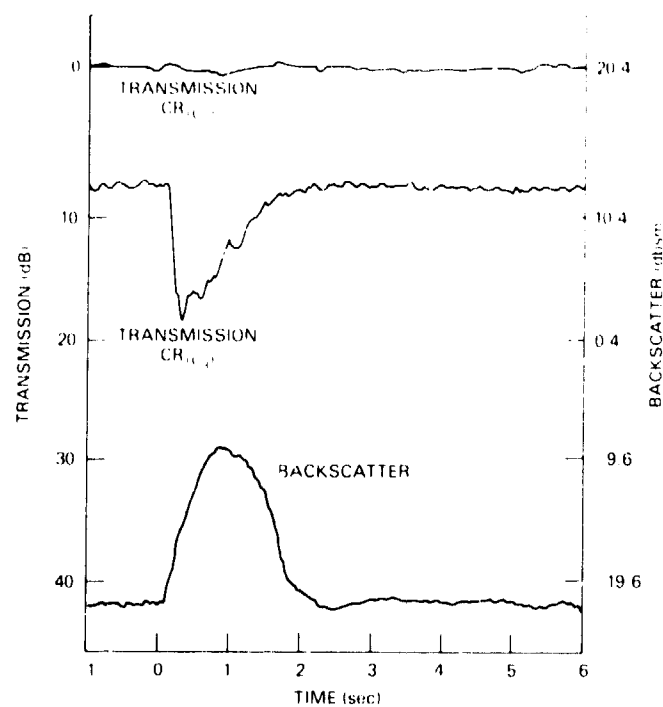
(b)



(c)

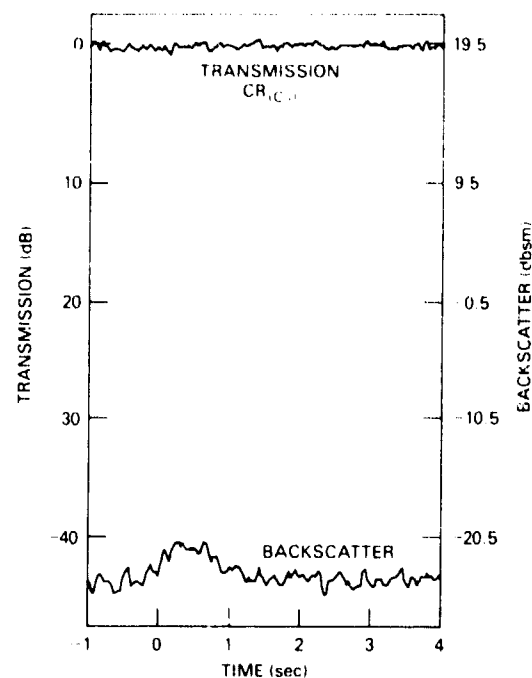
Figure 12. Transmission, backscatter vs. time for three subsurface-detonated 155-mm projectiles at locations: (a) CL, (b) 10 m East of CL, and (c) 20 m East of CL.

B4 105mm



(a)

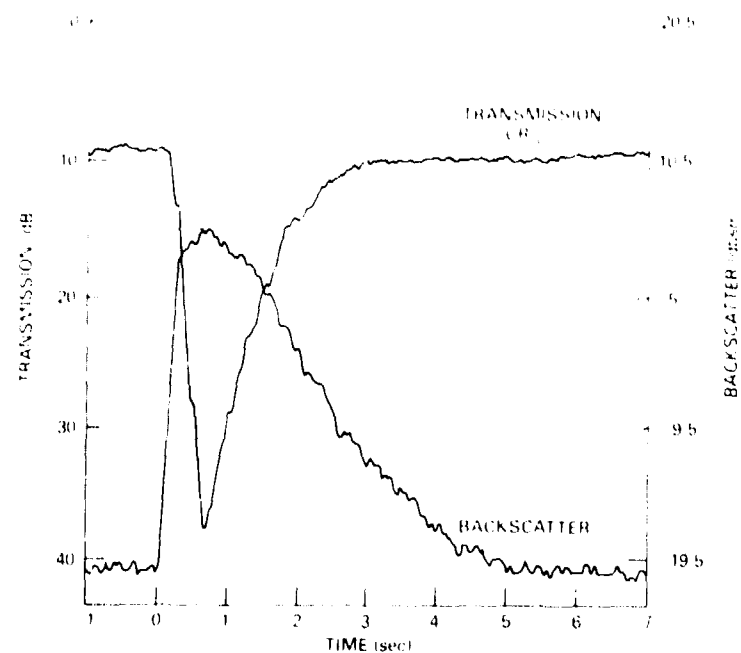
B6 105mm



(b)

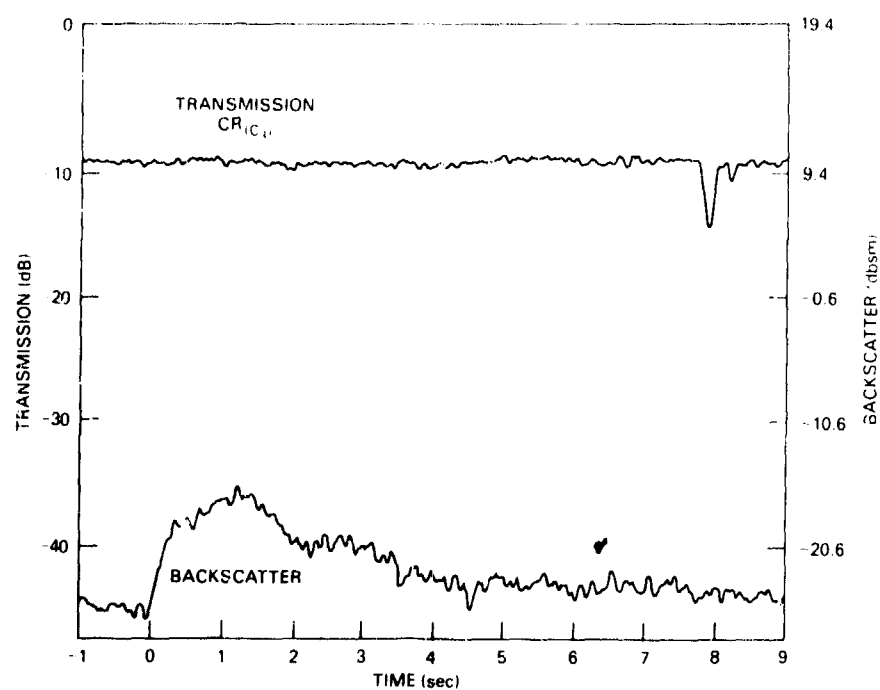
Figure 13. Transmission, backscatter vs. time for two surface-detonated 105-mm projectiles at locations: (a) CL, and (b) 10 m East of CL.

B3 105mm



(a)

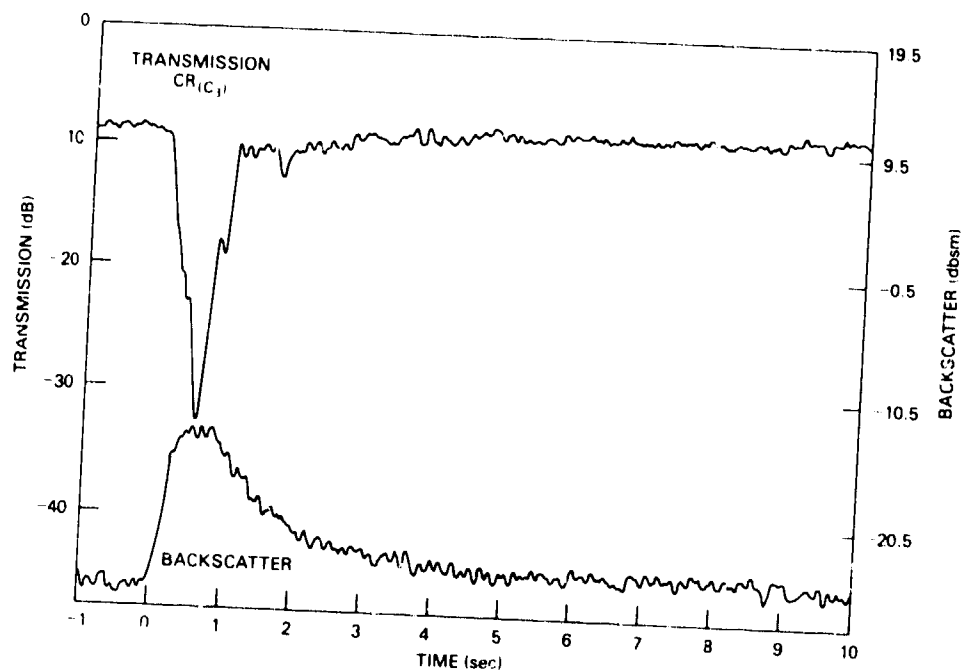
B5 105mm



(b)

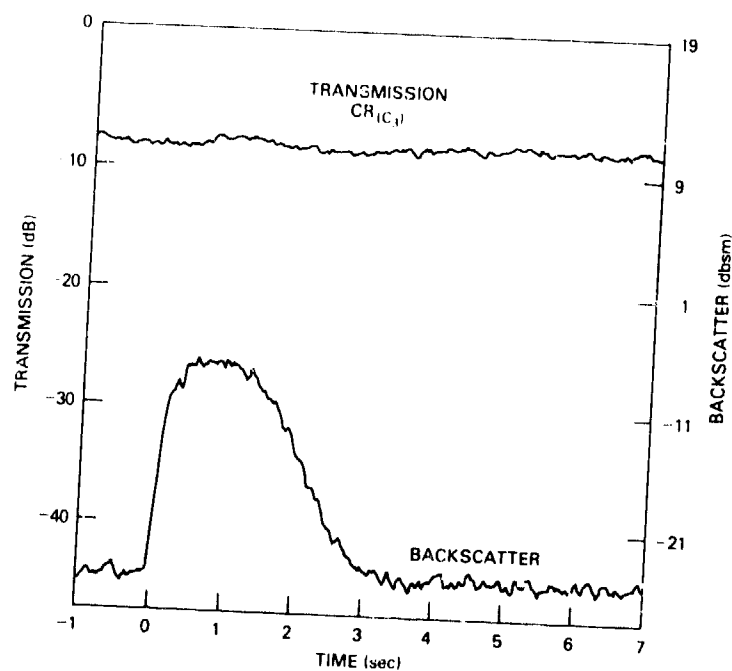
Figure 14. Transmission, backscatter vs. time for two subsurface-detonated 105-mm projectiles at locations: (a) CL, and (b) 10 m East of CL.

E1 C4



(a)

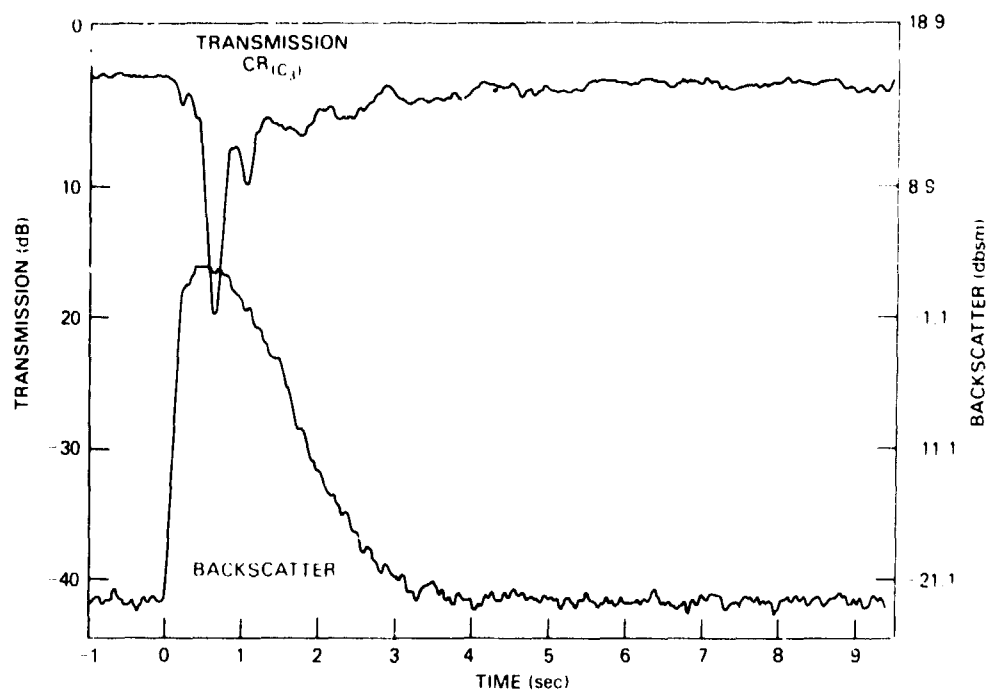
E3 C4



(b)

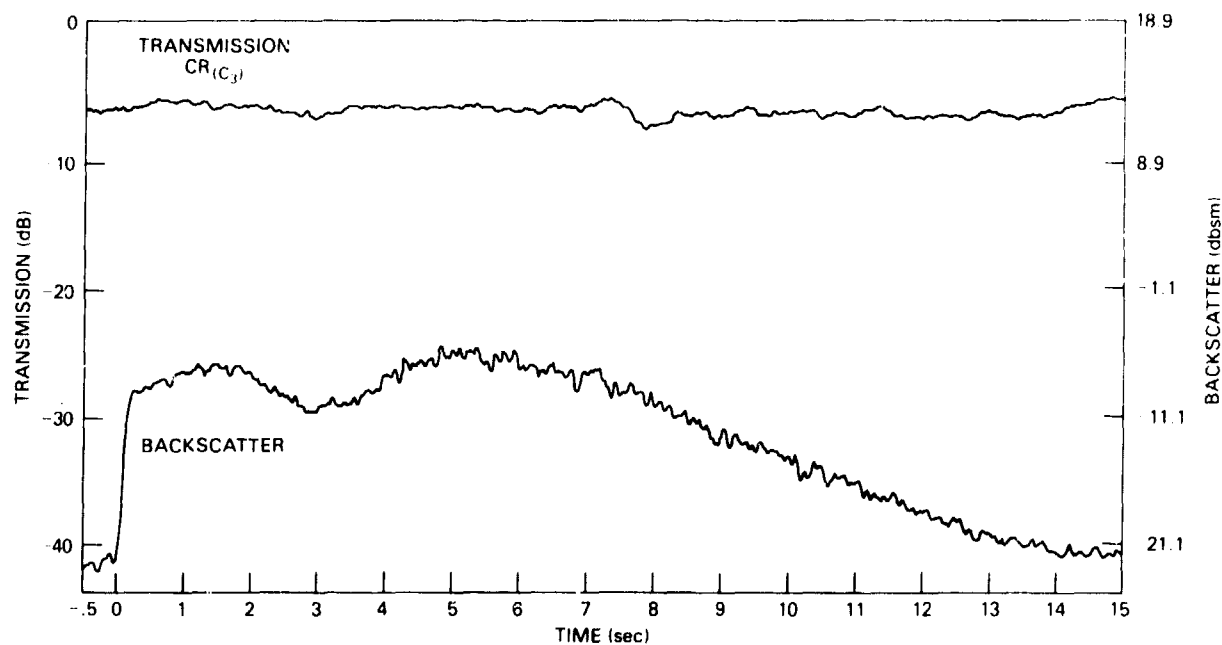
Figure 15. Transmission, backscatter vs. time for two surface-detonated C4 explosives at locations: (a) CL, and (b) 10 m East of CL.

E5 C4



(a)

E6 C4



(b)

Figure 16. Transmission, backscatter vs. time for two subsurface-detonated C4 explosives at locations: (a) CL, and (b) 10 m East of CL.



from the centerline, it is apparent that the rise time becomes slower and is dependent on displacement. This is attributed to the additional time required for the wind to carry the explosive debris into the principal portion of the millimeter wave radar beam on the centerline.

Examples of the data acquired for 105-mm surface and subsurface-detonated projectiles are given in Figures 13 and 14, respectively. Since there were negligible values of attenuation and backscatter recorded when a 105-mm projectile was detonated 20 m away from the centerline, data have not been included for this case. Transmission data for both paths 2 and 3 have been shown with the data for path 3 being displaced from the unity transmission line for clarity. The large variations in the values of attenuation recorded for these two paths can be attributed to the nonhomogeneity of the resultant cloud. As would be expected, the cloud density varies inversely with height above ground zero.

Examples of the data obtained for surface and subsurface-detonated C4 explosives are presented in Figures 15 and 16, respectively. There were no millimeter wave measurements performed during the detonation of C4 explosives positioned 20 m away from the centerline and, therefore, no data have been shown for this case.

In Figure 17 the mean values of peak backscatter and duration for surface detonations have been compared with those values obtained for subsurface detonations. The dependence of backscatter and duration on displacement has also been illustrated. From this figure two observations can be readily made:

1. The mean duration of the backscatter was greater for subsurface detonations than for surface detonations of 155-mm and 105-mm projectiles.
2. On the average, significantly larger values of backscatter were measured when a 155-mm or 105-mm projectile was detonated below the surface than when it was detonated on the surface.

A listing of the average values of maximum two-way attenuation and the associated recovery time have been shown in Table 3. Again a number of observations can be readily made:

1. Larger values of two-way attenuation and associated recovery time were measured when a 155-mm or 105-mm projectile was detonated below the surface than those values which were measured when a projectile was detonated on the surface.
2. Negligible values of two-way attenuation were recorded when a projectile was exploded only 10 m away from the beam center.

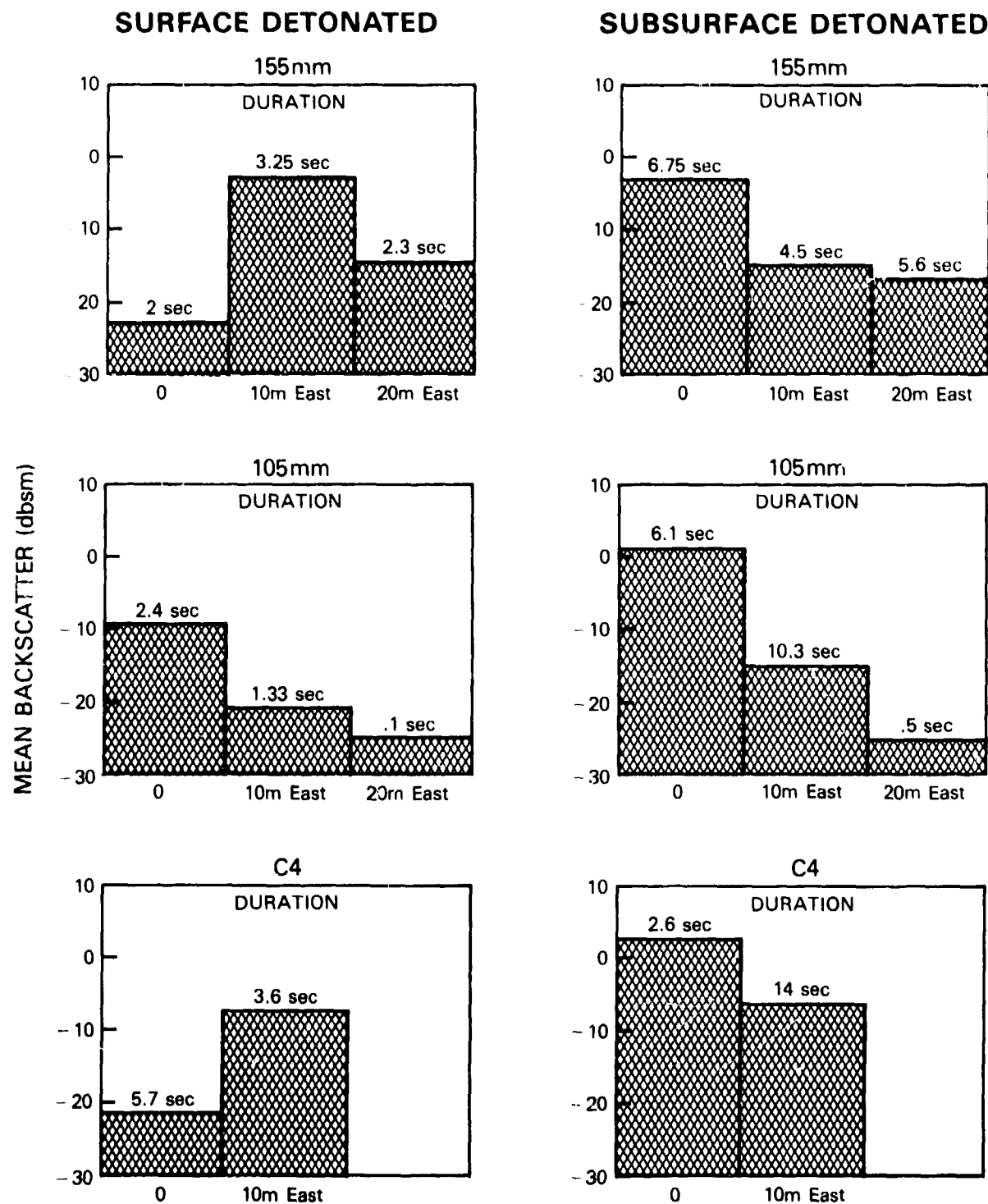


Figure 17. A comparison of the mean values of peak backscatter and duration obtained for surface explosives with those values for subsurface explosions.

**TABLE 3**  
**A LISTING OF THE AVERAGE VALUES OF MAXIMUM TWO-WAY ATTENUATION AND ASSOCIATED**  
**RECOVERY TIME WHICH WERE RECORDED DURING DIRT II**

	SURFACE				SUBSURFACE			
	CL PATH 2/PATH 3 [db(sec)]/[db(sec)]	10M PATH 2/PATH 3 [db(sec)]/[db(sec)]	20M PATH 2/PATH 3 [db(sec)]/[db(sec)]	CL PATH 2/PATH 3 [db(sec)]/[db(sec)]	10M PATH 2/PATH 3 [db(sec)]/[db(sec)]	20M PATH 2/PATH 3 [db(sec)]/[db(sec)]		
A TESTS	1.38 (.1)/—	1.4 (0.8)/—	0 (0)/—	25.28 (5.9)/—	0.1 (4.6)/—	0.6 (0.9)/—		
# OF TESTS	4	2	1	2	1	2		
B TESTS	—/10.7 (1.8)	0 (0)/—	—/0 (0)	10.1 (2.23)/ 17.8 (5.5)	—/2.5 (.35)	—/0 (0)		
# OF TESTS	1	2	2	2	2	2		
E TESTS	—/13.7 (.7)	0 (0)/0 (0)	—/—	9.5 (1.1)/ 23.5 (5.8)	—/0.1 (0.6)	—/—		
# OF TESTS	2	1	0	3	1	0		

3. Whenever it was possible to make simultaneous measurements along paths 2 and 3, path 3 which was 4.5 m above the ground had significantly larger values of attenuation than path 2 which was 11.1 m above the ground.

## VI. SUMMARY

The Atmospheric Science Laboratory's DIRT II test provided the opportunity to perform 95 GHz millimeter wave radar transmission and backscatter measurements during singular live firings and static detonations of 155-mm and 105-mm high-explosive projectiles. The following summarizes the results:

1. The debris, or cloud, which was generated by the explosion and produces measurable backscatter, extends for 30 m to 45 m, and moves in the direction of the wind.

2. The scattering cross section and attenuation associated with an explosion are dependent upon the moisture content and type of the soil, whereas the duration and recovery time are dependent upon the wind velocity.

3. The mean value of peak backscatter and the mean duration were greater for the ARTY A series (-16.5 dbsm, 3.2 s) than for the ARTY B series (-25.31 dbsm, 2.0 s) and negligible values of attenuation were recorded for both series.

4. The mean value of the peak backscatter and the mean duration were greater for subsurface detonations than for surface detonations of 155-mm and 105-mm projectiles. On axis the mean value of peak backscatter and the mean duration measured for 155-mm and 105-mm subsurface detonated projectiles were -2.7 dbsm for 6.75 s and 1.81 dbsm for 6.1 s, respectively.

5. The mean value of two-way attenuation and the mean recovery time were also greater for subsurface detonations than for surface detonations of 155-mm and 105-mm projectiles. The largest mean value of two-way attenuation and recovery time measured for 155-mm and 105-mm detonated projectiles were 25.28 dB for 5.9 s and 10.1 dB for 2.23 s, respectively.

6. Negligible values of two-way attenuation were recorded when a projectile was not exploded on the beam center.

7. Whenever it was possible to make simultaneous transmission measurements along paths 2 and 3, path 3 which was 4.5 m above the ground had significantly larger values of attenuation than path 2 which was 11.1 m above the ground.

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